ORNAMENT

Ontario Road Noise
Analysis Method for Environment
and Transportation

November 1988

Environment
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Ontario Road Noise
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November 1988

Noise Assessment and Systems Support Unit

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Ontario Road Noise Analysis Method for Environment and Transportation

1. Introduction

This document presents a concise description of a prediction method for road traffic noise based on traffic parameters, receiver description and topographical features. The Ministry of the Environment will use this method to assess noise impact from existing roadways on proposed residential land uses, for an assessment of roadway projects, and to establish the ambient noise level criterion for the purposes of approval of new noise sources or for complaint investigation. The method enhances the previous prediction method, published by this Ministry in "Guidelines for Road Traffic Assessment, December 1986".

Based on a model developed by the U.S. Federal Highway Administration, ORNAMENT was prepared by the Technical Sub-committee of an Advisory Committee on Road Traffic Noise, established by this Ministry in 1988. The sub-committee's members were: H. Gidamy (chairman), C.T. Blaney, J.E. Coulter, M. DeLint, L.G. Kende, A.D. Lightstone, J.D. Quirt, and V. Schroter.

The general concept of the method is to evaluate a reference sound level and adjust it by a series and combination of adjustments accounting for the gradient of the roadway, the pavement surface, the distance between the road and the receiver, the topography and any shielding obstructing the sound path. In comparison with the '86 prediction method, the basic evaluation of the reference sound level remains the same but the majority of the adjustments have been modified. The text of this document identifies those parts that have undergone modifications by specifying "CHANGE" in the title of the appropriate sections.

The validity of the prediction method is for source-to-receiver distances from 15 m to about 500 m but in the range from 200 m to 500 m, the accuracy of the prediction decreases. For distances greater than 500 m, use of this method is not recommended. Other limitations are a minimum posted speed of 40 km/h and a minimum traffic volume of 40 vehicles per hour. The prediction accuracy also decreases when the roadway includes interchanges and ramps, in cases of highly irregular topography, and where substantial differences exist between the speed of cars and trucks.

2. Assessment of Noise Impact

The prediction scheme described in this document yields the one-hour equivalent sound level at a point of reception, i.e receiver position, which can be used to define the ambient sound level for the purposes of complaint investigation or approval of new noise sources. In case impact assessment of road traffic noise on planned land uses such as residential subdivisions, the descriptors are the 24-hour equivalent sound level for freeways, and the 16-hour day-time and the 8-hour night-time sound level for other roads. Conversion from the one-hour sound level to the longer term level is a function of the day-night traffic volume split: 90% - 10%, 85% - 15% and 67% - 33% are the recommended distributions for regional roads, provincial roads and freeways respectively. Details of the assessment were described in a Ministry publication "Environmental Noise Assessment in Land Use Planning, 1987".

The road traffic noise impact is typically evaluated at two receiver locations:

- Outdoor Living Area, 3 m from facade and 1.5 m above ground, for the purposes of an appropriate outdoor sound level;
- 2nd storey window, 4.5 m above ground, for the purposes of an appropriate indoor sound level.

As described in the publication "Environmental Noise Assessment in Land Use Planning, 1987", the calculated sound level has to be adjusted for source/receiver geometry, in order to account for differing orientations of the road and the receiver. However, unlike the '87 method, corrections to the calculated sound levels for sound reflection from building facades are not required.

Where the noise impact exceeds the applicable criteria, mitigation measures such as noise barriers, special windows or walls, and central air conditioning may be necessary. For the purposes of assessing the noise impact, an obstacle may only be considered as a "noise barrier" when the obstacle breaks the line of sight between the source an the receiver.

3. Basic Formulation

CHANGE

The one-hour equivalent sound level, L_{eq}, at a point of reception generated by vehicles travelling on a section (segment) of a roadway is given by:

$$L_{eq} = L_{ref} + A_v + A_d + A_f + A_p + A_s \qquad \ldots (1)$$

where

L_{ref} is the Reference sound level;
$A_v = 10 \log(V/V_{ref})$ Volume adjustment;
$A_d = 10\,(1+\alpha) \log(D_{ref}/D)$ Distance Adjustment;
A_f is the Finite segment adjustment;
A_p is the Pavement surface adjustment;
$A_s = A_b$ or A_h or A_w Shielding adjustment.
where A_b is the barrier attenuation adjustment;
A_h is the adjustment for rows of houses;
A_w is the adjustment for dense woods.

The road segment is a section of the roadway defined as follows:

(i) the width must not be more than 4 road lanes;

(ii) parameters defining the L_{eq} must be the same within the segment; these include road alignment, road gradient, pavement surface, ground surface and shielding.

The method assumes three vehicle categories:

- automobiles: passenger vehicles with 2 axles and gross weight less than 4,500 lb;
- medium trucks: 2 axles and 6 wheels, gross weight between 4,500 lb and 12,000 lb (includes city buses);
- heavy trucks: 3 or more axles, gross weight greater than 12,000 lb (includes inter-city buses).

The symbols used in the above expression are defined as follows:

V	total hourly traffic volume;
V_{ref}	reference traffic volume of 40 vehicles per hour;
D	perpendicular distance from the receiver to the centre line of the road segment in metres (m);
D_{ref}	reference distance of 15 m;
α	ground absorption coefficient.

The total one-hour equivalent sound level at a point of reception, resulting from several road segments, is given by a logarithmic addition of contribution from the individual road sections:

$$L_{eq} = 10 \log [10^{L_{eq1}/10} + 10^{L_{eq2}/10} + 10^{L_{eq3}/10} + ..] \quad ...(2)$$

where L_{eq1}, L_{eq2}, and L_{eq3} are the sound levels produced by each roadway section, calculated using expression (1).

4. Reference Sound Level

The reference sound level is the sound level produced by a reference traffic volume at a reference distance from the road:

$$L_{ref} = 10 \log \sum_{i=1}^{3} \{ K_g P_i 10^{(L_o)_i/10} \} + 10 \log V_{ref} + 10 \log D_{ref} - 10 \log S - 25 \quad ... (3)$$

where	L_{ref} is	the reference hourly sound level;
	$(L_o)_i$	the reference energy mean emission level of i^{th} vehicle class;
	P_i	the percentage of i^{th} vehicle class, expressed as fraction of the total volume;
	K_g	the road gradient adjustment factor for heavy trucks, see Table 1; K_g = 1, automobiles and medium trucks; = 1, elevation change < 6m & grade < 2%;
	S	the posted speed limit in km/h.

The reference energy mean emission levels of the three vehicle categories, automobiles (A), medium trucks (MT), and heavy trucks (HT), are given by:

$$
\begin{aligned}
(L_o)_A &= 38.1 \log(S) - 2.4 \\
(L_o)_{MT} &= 33.9 \log(S) + 16.4 \qquad \ldots (4) \\
(L_o)_{HT} &= 24.6 \log(S) + 38.5
\end{aligned}
$$

The reference sound levels are given in Tables 3,4,5 and 6; the reference energy mean emission levels are plotted against the posted speed limit S in Figure 1.

5. Road Gradient Adjustment

This adjustment is applied to heavy trucks travelling in the upgrade direction when road gradient is more than 2 % and the change in elevation is more than 6 m. The adjustment is in the form of a multiplication factor K_g applied to number of trucks travelling up the grade. Values of this factor are tabulated in Table 1.

6. Traffic Volume Adjustment

The traffic volume adjustment is given by

$$A_v = 10 \log(V/V_{ref}) = 10 \log (V/40) \qquad \ldots(5)$$

where V is the total traffic volume.

Figure 2 and Table 2 present the volume adjustment.

7. Pavement Surface Adjustment

CHANGE

This adjustment is applicable when the posted speed limit is equal or greater than 80 km/h. The values of the adjustment are given in Table 12.

8. Distance Adjustment CHANGE

The distance adjustment is given by the following:

$$A_d = 10\ (1 + \alpha)\ \log(D_{ref}/D) \qquad \ldots(6)$$

where

1. Reflective Surfaces (hard ground)

$$\alpha = 0$$

2. Absorptive Surfaces (soft ground)

$$\alpha = 0.66\ , \qquad h_{eff} \le 3\text{ m}$$

$$\alpha = 0.75\ \left(1 - \frac{h_{eff}}{25}\right)\ , \qquad 3 < h_{eff} \le 25\text{ m}$$

$$\alpha = 0\ , \qquad h_{eff} > 25\text{ m}$$

where h_{eff} is the total effective height.

Distance adjustment values are shown in Table 7 and Figure 3.

8.1 Total Effective Height CHANGE

The total effective height (h_{eff}) is defined as a function of the receiver height (r), effective source height (s), barrier height (h), height of woods (w), and the change of ground elevation (e). For a flat ground of any grade, for example, the total effective height is given by

$$h_{eff} = s + r$$

Definitions of the total effective height are given in Figure 4. The actual topographical situations should, where possible, be modelled by one of the cases shown in Figure 4. Configurations which cannot be modelled by one of the cases have to be assessed by other means.

Application of Figure 4 is restricted to topographies for which the horizontal distances are much greater than the vertical distances. In cases where the vertical distance, such as the elevation, is of the same order of magnitude as any of the horizontal distances, other means of assessment are necessary.

8.2 Receiver and Source Heights

The height of the receiver above ground is not specifically defined in the sound level prediction method. However, for the purposes of the noise impact on single family dwellings and townhouse units, the following receiver heights are used:

1.5 m, defining the outdoor living area;
4.5 m, defining a 2nd storey window.

The source height is represented by an effective height of the combined traffic sound source above the road surface. The following expression defines the effective source height:

$$\begin{aligned} s &= 0.5\ \text{m}, && P_{HT} < 0.01 \\ &= \sqrt[4]{100\ P_{HT}}, && 0.01 \leq P_{HT} \leq 0.30 \\ &= 2.4\ \text{m}, && P_{HT} > 0.30 \end{aligned}$$

where P_{HT} is the percentage of heavy trucks, unadjusted by the gradient factor, expressed as a fraction of the total volume.

Table 8 presents the effective source height in a tabular form.

9. Finite Segment Adjustment **CHANGE**

The adjustment for finite segment, i.e. finite length of the roadway section, is given by the following expression

$$A_f = 10 \log \left\{ \frac{1}{\pi} \int_{\phi_1}^{\phi_2} \cos^{\alpha} \phi \ d\phi \right\} \qquad \ldots(7)$$

The angles ϕ_1 and ϕ_2, expressed in radians, define the extent of the road segment at the receiver location, see Table 10.

The expression applies universally to all surfaces; however, in case of a reflective surface, the expression simplifies to

$$A_f = 10 \log \{ \frac{\phi_2 - \phi_1}{\pi} \} , \text{ Reflective surface} \quad ...(8)$$

Figure 5 and Table 9 present the finite segment adjustment for reflective ground. Figures 6.1 through to 6.4, and Tables 11.1 through to 11.4 present the adjustment for absorbent ground.

10. Shielding Adjustment CHANGE

The shielding adjustment is found from the shielding effect provided by three potential obstacles:

- barrier
- rows of houses
- dense woods

In case of a combination of two or three obstacles, such as woods and houses, or barrier and houses, the individual adjustments are evaluated in the absence of the other, i.e. as if the other were not present, and the value of the single largest adjustment defines the shielding adjustment:

$$A_s = A_b \text{ or } A_h \text{ or } A_w , \quad \text{whichever is largest}$$

10.1 Adjustment for Dense Woods CHANGE

An adjustment may be made to account for the presence of trees providing they are very dense, i.e no visual path between the road and the receiver, and the height of the trees is a minimum of 5 m above the line of sight. Table 13 presents the adjustment versus the depth of the trees.

When this adjustment is used in combination with the distance adjustment for absorbent ground, the effective height of the source and receiver must be increased by twice the minimum tree height specified above, i.e. by 10 m, see Figure 4.

10.2 Barrier Attenuation

Barrier attenuation is given by the following expressions:

...(9)

$$A_b = 0 \text{ dB}, \qquad \text{for } (N_o)_i \cos \phi \le -0.1916$$

$$A_b = 10 \log \left\{ \frac{1}{\phi_2 - \phi_1} \int_{\phi_1}^{\phi_2} \frac{\tan^2 \sqrt{2\pi \, |N_o|_i \cos \phi}}{\sqrt{10} \quad 2\pi \, |N_o|_i \cos \phi} \, d\phi \right\},$$

$$\text{for } -0.1916 \le (N_o)_i \cos \phi \le 0$$

$$A_b = 10 \log \left\{ \frac{1}{\phi_2 - \phi_1} \int_{\phi_1}^{\phi_2} \frac{\tanh^2 \sqrt{2\pi \, (N_o)_i \cos \phi}}{\sqrt{10} \quad 2\pi \, (N_o)_i \cos \phi} \, d\phi \right\},$$

$$\text{for } 0 \le (N_o)_i \cos \phi \le 5.03$$

$$A_b = 20 \text{ dB}, \qquad \text{for } (N_o)_i \cos \phi \ge 5.03$$

where N_o is Fresnel Number, $N_o = 2.915 \times$ (Path Length Difference)

Barrier attenuation may only be utilized in the calculation when the barrier breaks the line of sight between the source and the receiver, i.e. for positive Fresnel numbers. Tables B1 and B2 present the attenuation of finite barriers.

10.3 Rows of Houses Adjustment

CHANGE

An adjustment to account for the presence of rows of houses between the source and the receiver is dependent on the percentage of gaps between the houses and on the source-receiver distance; Table 14 and Figure 7 give the value of the adjustment. When the road and the receiver are separated by more than one row of houses, 1.5 dB should added for each additional row.

In general, the adjustment applies to both the receiver on the ground as well as the receiver at the 2nd storey window. However, when the screening is being provided by a row of single storey houses such as bungalows, the adjustment may only be applied to the ground level receiver. Furthermore, the adjustment is only applicable in the context of a subdivision, for a receiver between rows of houses or behind the last row. The adjustment is not applicable for large row-to-receiver distances.

When this adjustment is used in combination with the distance adjustment for absorbent ground, the total effective height is given by the effective source height and receiver height.

11. Conclusions

The prediction method described in this document, which has been prepared by a group of experts representing the research community, the consulting community and the regulatory agencies, is based on the best information available to date. It presents a straight forward technique of evaluating the noise level at a point of reception, without the necessity of solving complicated mathematical equations.

The requirement for a simple, modular nature of the prediction has necessitated a series of compromise solutions. The distance adjustment, for example, is considered accurate only to a distance of 200 m from the road; at greater distances, the accuracy decreases and the method is not recommended for distances greater than 500 m. Other compromises were reached regarding the effect of receiver height on the distance adjustment, regarding the adjustment for rows of houses and the adjustment for dense woods. Nevertheless, the effect of these compromises is marginal and the method is considered accurate in most realistic situations.

In cases where the use of Ornament is not appropriate, such as in complex situations including highly irregular topography or at large distances, other methods including long term noise measurements may better describe the noise impact.

12. Acknowledgement

The following people have participated in developing ORNAMENT:

P. Joseph, Ministry of the Environment	Chairman, Advisory Committee
H. Gidamy, S.S. Wilson & Associates	Chairman, Technical Subcommittee
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V. Schroter, Ministry of the Environment	

V. Schroter
November 3, 1988

TABLE 1

Adjustment to Percentage of Heavy Trucks on Up-Hill Grades

Road Gradient %	Adjustment Factor (Multiplicative)
0 to less than 2	1
2 to less than 5	1.5
5 to less than 7	2
Over 7	3

TABLE 2

Adjustment to the Reference Hourly Sound Level for Traffic Volume

Use the nearest listed value when the actual value of volume is not listed

Hourly Traffic Volume	Adjustment (Additive) dBA	Hourly Traffic Volume	Adjustment (Additive) dBA	Hourly Traffic Volume	Adjustment (Additive) dBA
40	0	315	9	2000	17
50	1	400	10	2500	18
63	2	500	11	3150	19
80	3	630	12	4000	20
100	4	800	13	5000	21
125	5	1000	14	6300	22
160	6	1250	15	8000	23
200	7	1600	16	10000	24
250	8				

Given the posted speed limit of traffic in km/h and the total percentage of trucks (including medium and heavy trucks), the following Tables 3 and 4 provide the predicted Reference Hourly Sound Level at 15 m from the centreline of a road section with a total traffic volume of 40 vehicles per hour (vph). Use the nearest listed value when the actual value of speed or truck percentage is not listed.

TABLE 3

Reference Hourly Sound Level in dBA at 15 m and 40 vph: Percentage of Medium Trucks in the Range of 0 - 25 %.

POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	48	49	51	53	54	55	57	58	59	60	61	62	63	64
50	50	51	53	54	56	57	58	59	60	61	62	63	65	66
60	52	53	55	56	57	58	59	60	61	62	63	65	66	67
70	54	55	56	57	58	59	60	61	62	63	65	66	67	68
80	55	56	57	58	59	60	61	62	63	64	65	67	68	69
90	56	57	58	59	60	61	62	63	64	65	66	67	69	69
100	57	58	59	60	61	62	63	64	65	66	67	68	69	70

TABLE 4

Reference Hourly Sound Level in dBA at 15 m and 40 vph: Percentage of Medium Trucks in the Range of 26 - 50 %.

POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47	49	51	52	53	54	56	57	57	59	60	61	62	63
50	50	51	53	54	55	56	57	58	59	60	61	62	64	65
60	52	53	54	55	56	57	59	60	60	62	63	64	65	66
70	53	54	56	57	58	59	60	61	61	63	64	65	66	67
80	55	56	57	58	59	60	61	62	62	64	65	66	67	68
90	56	57	58	59	60	61	62	63	63	65	65	67	68	69
100	57	58	59	60	61	62	63	63	64	65	66	67	69	69

Given the posted speed limit of traffic in km/h and the total percentage of trucks (including medium and heavy trucks), the following Tables 5 and 6 provide the predicted Reference Hourly Sound Level at 15 m from the centreline of a road section with a total traffic volume of 40 vehicles per hour (vph). Use the nearest value when the actual value of speed or truck percentage is not listed.

TABLE 5

Reference Hourly Sound Level in dBA at 15 m and 40 vph:
Percentage of Medium Trucks in the Range of 51 - 75 %.

POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47	48	50	51	52	53	54	55	56	57	58	59	61	62
50	49	50	52	53	54	55	56	57	58	59	60	61	62	63
60	51	52	53	54	56	56	57	58	59	60	61	63	64	65
70	53	54	55	56	57	58	59	60	60	62	63	64	65	66
80	55	55	56	57	58	59	60	61	62	63	64	65	66	67
90	56	57	58	58	59	60	61	62	63	64	65	66	67	68
100	57	58	59	59	60	61	62	63	63	65	65	67	68	69

TABLE 6

Reference Hourly Sound Level in dBA at 15 m and 40 vph:
Percentage of Medium Trucks in the Range of 76 - 100 %.

POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	46	47	48	49	50	51	52	53	54	55	56	57	58	59
50	49	50	51	52	53	53	54	55	56	57	58	59	60	61
60	51	52	53	53	54	55	56	57	58	59	60	61	62	63
70	53	53	54	55	56	57	58	58	59	60	61	62	63	64
80	54	55	56	56	57	58	59	60	60	61	62	64	65	66
90	56	56	57	58	59	59	60	61	62	63	64	65	66	67
100	57	57	58	59	60	60	61	62	63	64	65	66	67	68

TABLE 7

Adjustment for Distance
Distance Measured from Centreline of Road to Point of Reception

Total Effective Height (m)		**Perpendicular Distance from Centreline of Road to Point of Reception (m)**												
		15	20	30	40	50	60	80	100	120	150	200	250	500
h_{eff}	α	Adjustment in dBA for Non-Reflective Surfaces												
1.5	0.66	0	-2	-5	-7	-9	-10	-12	-14	-15	-17	-19	-20	-25
2	0.66	0	-2	-5	-7	-9	-10	-12	-14	-15	-17	-19	-20	-25
3	0.66	0	-2	-5	-7	-9	-10	-12	-14	-15	-17	-19	-20	-25
4	0.63	0	-2	-5	-7	-9	-10	-12	-13	-15	-16	-18	-20	-25
6	0.57	0	-2	-5	-7	-8	-9	-11	-13	-14	-16	-18	-19	-24
8	0.51	0	-2	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-23
10	0.45	0	-2	-4	-6	-8	-9	-11	-12	-13	-15	-16	-18	-22
12	0.39	0	-2	-4	-6	-7	-8	-10	-11	-13	-14	-16	-17	-21
16	0.27	0	-2	-4	-5	-7	-8	-9	-10	-11	-13	-14	-16	-19
20	0.15	0	-1	-3	-5	-6	-7	-8	-9	-10	-12	-13	-14	-18
25	0.00	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
32	0.00	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
40	0.00	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
50	0.00	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
60	0.00	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
		Adjustment in dBA for Reflective Surfaces												
All Heights	0.00	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15

TABLE 8

Effective Source Height of Road Traffic

Unadjusted Percentage of Heavy Trucks in Total Flow (%)	Effective Source Height (m)
0	0.5
1	1.0
2	1.2
3	1.3
4	1.4
5	1.5
6-7	1.6
8-9	1.7
10-11	1.8
12-14	1.9
15-17	2.0
18-21	2.1
22-25	2.2
26-30	2.3
>30	2.4

TABLE 9

Adjustment for Road Element Size: Reflective Surfaces

Subtended Angle $ø_2 - ø_1$ (degrees)	Adjustment (dBA)	Subtended Angle $ø_2 - ø_1$ (degrees)	Adjustment (dBA)
180	0	50	-6
160	-1	45	-6
140	-1	40	-7
120	-2	35	-7
100	-3	30	-8
90	-3	25	-9
80	-4	20	-10
70	-4	15	-11
60	-5	10	-13
55	-5	5	-16

TABLE 10

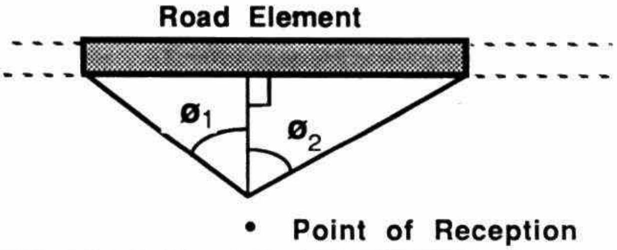
Angular Relationship between Road Elements and Receptor Locations

This table defines the angular relationship between a roadway element and a point of reception(observer) in terms of angles ϕ_1 and ϕ_2, expressed in degrees.

CASE 1

ϕ_1 is negative

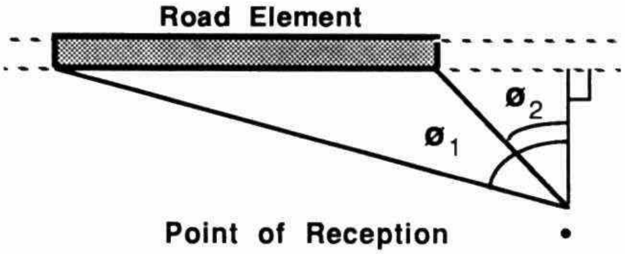
ϕ_2 is positive



CASE 2

ϕ_1 is negative

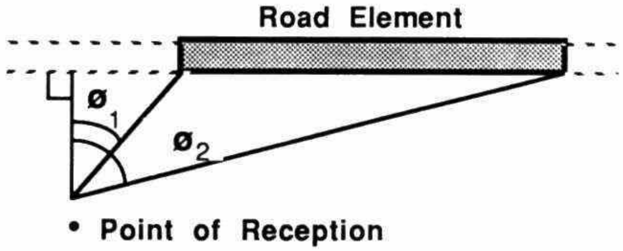
ϕ_2 is negative



CASE 3

ϕ_1 is positive

ϕ_2 is positive



SUBTENDED ANGLE of the road element at the point of reception:

$$\phi = \phi_2 - \phi_1$$

TABLE 11.1
Adjustment for Road Element Size

α = 0.1

Road Angles		ø2																	
		-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
		Adjustment in dBA																	
	-90	-14	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-0	-0	-0	-0
	-80	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-0	-0	-0
	-70	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-0	-0
	-60	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-0
	-50	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1
	-40	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2
	-30	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2
	-20	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2
	-10	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3
ø1	0	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3
	10	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4
	20	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4
	30	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6
	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7
	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8
	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14

TABLE 11.2
Adjustment for Road Element Size

$\alpha = 0.3$

Road Angles		ø2																	
		-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
		Adjustment in dBA																	
	-90	-16	-12	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-1	-0	-0
	-80	-	-14	-11	-9	-8	-6	-5	-5	-4	-3	-3	-3	-2	-2	-2	-1	-1	-0
	-70	-	-	-14	-10	-9	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-1	-1
	-60	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-1
	-50	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2
	-40	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2
	-30	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-2
	-20	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3
	-10	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3
ø1	0	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-4
	10	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5	-4
	20	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5
	30	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-6
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8	-7
	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8
	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-11	-10
	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-12
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16

TABLE 11.3
Adjustment for Road Element Size

$\alpha = 0.5$

Road Angles	ø2																	
	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
	Adjustment in dBA																	
-90	-18	-14	-11	-9	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-1	-1
-80	-	-16	-12	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-1	-1
-70	-	-	-14	-11	-9	-8	-6	-5	-5	-4	-3	-3	-3	-2	-2	-2	-2	-1
-60	-	-	-	-14	-11	-9	-7	-6	-5	-4	-4	-3	-3	-3	-2	-2	-2	-2
-50	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-2	-2	-2
-40	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-2	-2
-30	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-3
-20	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3
-10	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-4	-4
ø1 0	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5	-4	-4
10	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5	-5
20	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-6	-6
30	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8	-7	-7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-11	-9	-8	-8
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-11	-10	-9
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-12	-11
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16	-14
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-18

TABLE 11.4
Adjustment for Road Element Size

$\alpha = 0.66$

Road Angles	ø2																	
	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
	Adjustment in dBA																	
-90	-20	-15	-12	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-2	-1
-80	-	-16	-13	-10	-9	-7	-6	-5	-5	-4	-3	-3	-3	-2	-2	-2	-2	-2
-70	-	-	-15	-12	-9	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-2
-60	-	-	-	-14	-11	-9	-7	-6	-5	-5	-4	-3	-3	-3	-2	-2	-2	-2
-50	-	-	-	-	-14	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-2	-2	-2
-40	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-3	-2
-30	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-3
-20	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-4	-3	-3
-10	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5	-4	-4	-4
ø1 0	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5	-5	-4
10	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-6	-5	-5
20	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-7	-6	-6
30	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8	-7	-7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-11	-9	-9	-8
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-12	-10	-10
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-15	-13	-12
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16	-15
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-20

TABLE 12

Adjustment for Pavement Surface Type

Pavement Surface Type	Adjustment (dBA)
Typical asphalt (e.g. HL-1) or concrete	0
Open-graded friction course	-2.5
* Grooved concrete pavement	+ 7

* Not used on new highways

TABLE 13

Adjustment for Dense Woods

DENSE WOODS	
Depth of Woods between Source and Receiver (m)	**Attenuation (dBA)**
30	5
60	10
NOTE: Maximum attenuation allowed is 10 dBA	

TABLE 14
Adjustment For Rows Of Houses

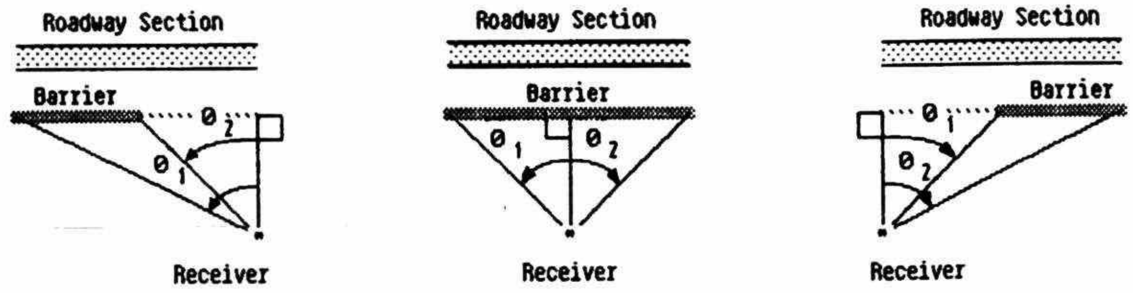
First Row of Houses					
Percentage of Row Occupied by Houses	Distance from Centreline of Road to Point of Reception (m)				
	30	60	120	240	480
	Adjustment in dBA				
10	-0	-0	-0	-0	-0
15	-1	-1	-1	-1	-1
20	-1	-1	-1	-1	-1
25	-1	-1	-1	-1	-1
30	-1	-1	-1	-1	-1
35	-2	-2	-2	-2	-2
40	-2	-2	-2	-2	-2
45	-2	-2	-2	-2	-2
50	-3	-3	-3	-3	-2
55	-3	-3	-3	-3	-3
60	-4	-4	-3	-3	-3
65	-4	-4	-4	-4	-3
70	-5	-5	-4	-4	-4
75	-5	-5	-5	-5	-4
80	-6	-6	-6	-5	-5
85	-7	-7	-6	-6	-5
90	-8	-8	-7	-7	-6
95	-10	-9	-9	-8	-7
Additional Rows of Houses					
Apply adjustment of -1.5 dBA for each successive row					

TABLE B1

Finite Barrier Index for Asymmetric Barriers

	θ_2, The Rightmost End Angle of the Barrier (degrees)																	
θ_1, The Leftmost End Angle of the Barrier (degrees)	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
-90	1	2	3	4	6	7	9	9	9	10	12	12	12	12	14	12	12	9
-80	-	5	8	10	10	14	15	15	18	18	19	19	19	19	19	19	18	12
-70	-	-	10	11	15	15	18	19	19	19	19	19	19	19	19	19	19	12
-60	-	-	-	15	18	19	19	19	20	20	20	20	20	20	20	19	19	14
-50	-	-	-	-	19	20	20	20	21	21	23	23	21	21	20	19	19	12
-40	-	-	-	-	-	20	21	23	23	23	23	23	23	21	20	19	19	12
-30	-	-	-	-	-	-	23	23	23	23	23	23	23	23	20	19	19	12
-20	-	-	-	-	-	-	-	23	23	23	23	23	23	23	20	19	19	12
-10	-	-	-	-	-	-	-	-	24	24	23	23	23	21	20	19	18	10
0	-	-	-	-	-	-	-	-	-	24	23	23	23	21	20	19	18	9
10	-	-	-	-	-	-	-	-	-	-	23	23	23	20	19	19	15	9
20	-	-	-	-	-	-	-	-	-	-	-	23	21	20	19	18	15	9
30	-	-	-	-	-	-	-	-	-	-	-	-	20	20	19	15	14	7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	19	18	15	10	6
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	11	10	4
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	8	3
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Angular Relationship between Barrier Sections and the Receiver



θ_1 is negative
θ_2 is negative

θ_1 is negative
θ_2 is positive

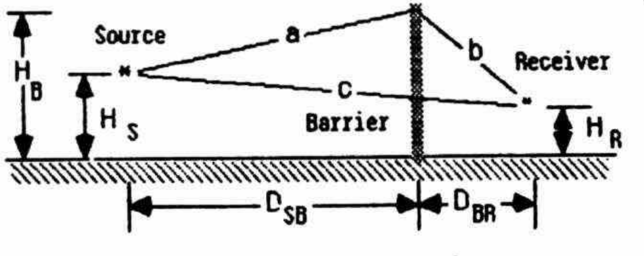
θ_1 is positive
θ_2 is positive

NOTES: 1) Where angles are not found in the table use the nearest listed value.

TABLE B2

Barrier Attenuation for Various Values of Finite Barrier Index

Path Length Difference (m)		Finite Barrier Index																			
		1	2	3	4	5	6	7	8	9	10	11	12	14	15	18	19	20	21	23	24
		Barrier Attenuation (dBA)																			
Barrier does not interrupt the line of sight	0.34	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.17	4	3	2	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	0.07	5	4	4	4	4	3	3	3	2	2	2	1	1	1	1	1	1	1	0	0
	0.05	5	5	4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2	2	1
	0.03	5	5	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
	0.02	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	0.00	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Barrier Does Interrupt the Line of Sight	0.03	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7
	0.10	5	6	6	6	6	7	7	7	7	7	7	7	7	8	8	8	8	8	9	9
	0.17	6	6	7	7	7	7	7	7	8	8	8	8	8	9	9	9	9	10	10	11
	0.24	6	6	7	7	7	8	8	8	9	9	9	9	9	9	10	10	10	11	11	12
	0.28	6	7	8	8	8	9	9	9	9	9	9	10	10	10	10	11	11	12	12	12
	0.34	6	7	8	8	8	9	9	9	10	10	10	10	10	11	11	12	12	13	13	13
	0.52	7	8	8	9	9	10	10	10	11	11	12	12	12	12	13	13	14	14	14	15
	0.69	7	8	9	10	10	10	11	11	12	12	13	13	13	13	14	14	15	15	16	16
	1.03	8	9	10	11	12	12	12	13	13	14	14	14	15	15	15	16	17	17	18	18
	1.38	9	10	11	12	13	13	13	14	14	15	15	15	16	16	17	17	18	18	19	19
	1.70	9	11	12	13	14	14	14	15	15	16	16	16	17	17	18	18	19	19	20	20
	2.06	10	11	13	14	14	14	15	16	16	16	16	16	17	18	18	19	20	20	20	20
	2.75	11	13	14	15	15	15	16	16	16	17	17	17	18	19	19	19	20	20	20	20
	3.44	11	13	14	15	16	16	16	17	17	18	18	18	18	19	19	20	20	20	20	20
	5.16	12	14	15	16	17	17	17	18	18	18	18	18	19	20	20	20	20	20	20	20
	6.88	13	15	16	17	17	18	18	18	18	19	19	19	19	20	20	20	20	20	20	20



Barrier, Source and Receiver Configuration

$$PLD = a + b - c$$

Where

$$a = \sqrt{D_{SB}{}^2 + (H_B - H_S)^2}$$

$$b = \sqrt{D_{BR}{}^2 + (H_B - H_R)^2}$$

$$c = \sqrt{(D_{SB} + D_{BR})^2 + (H_S - H_R)^2}$$

NOTE: 1) Where the calculated PLD is not found in the table use the nearest listed value.

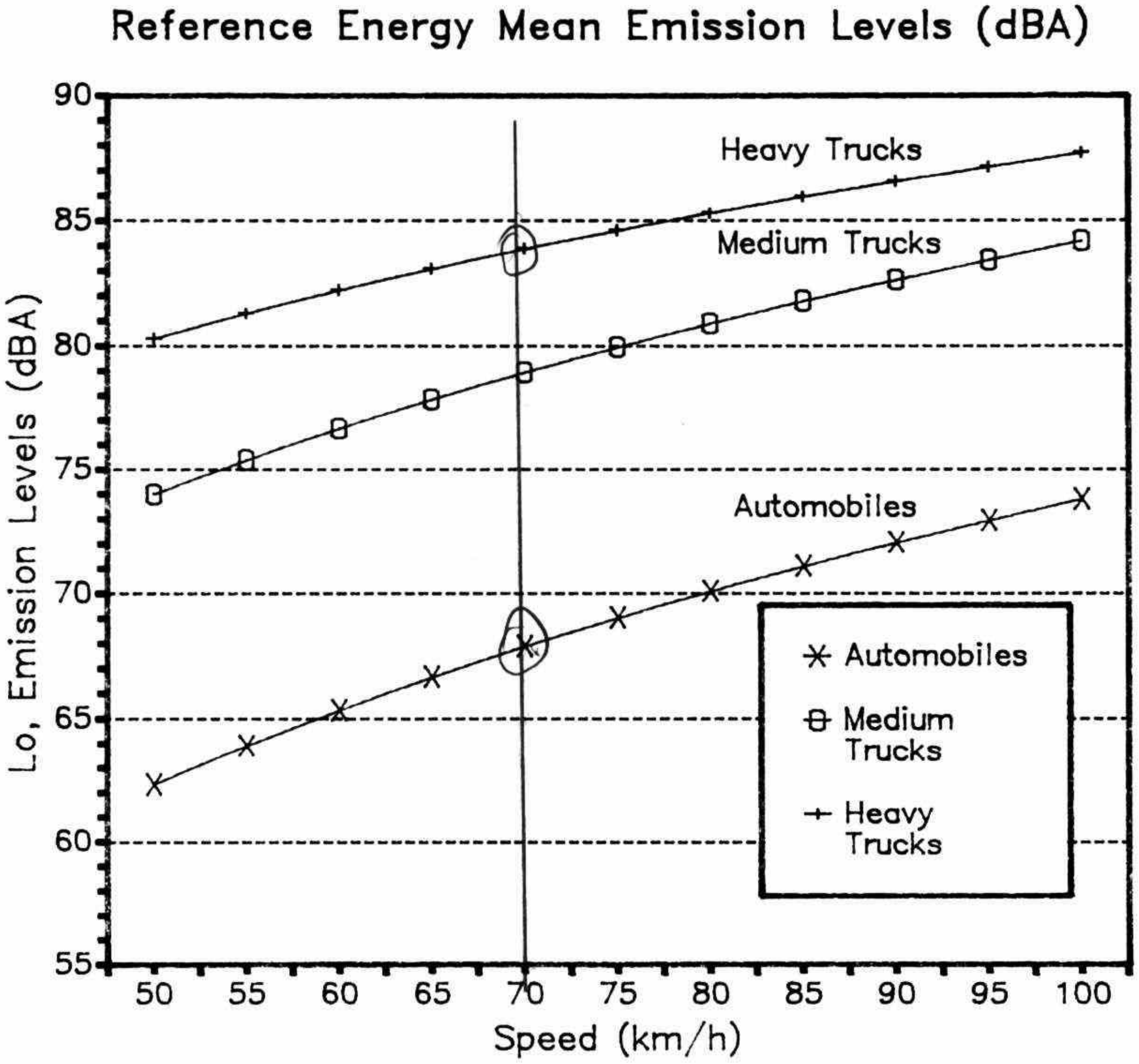


Figure 1: Reference Energy Mean Emission Levels of Automobiles, Medium Trucks and Heavy Trucks

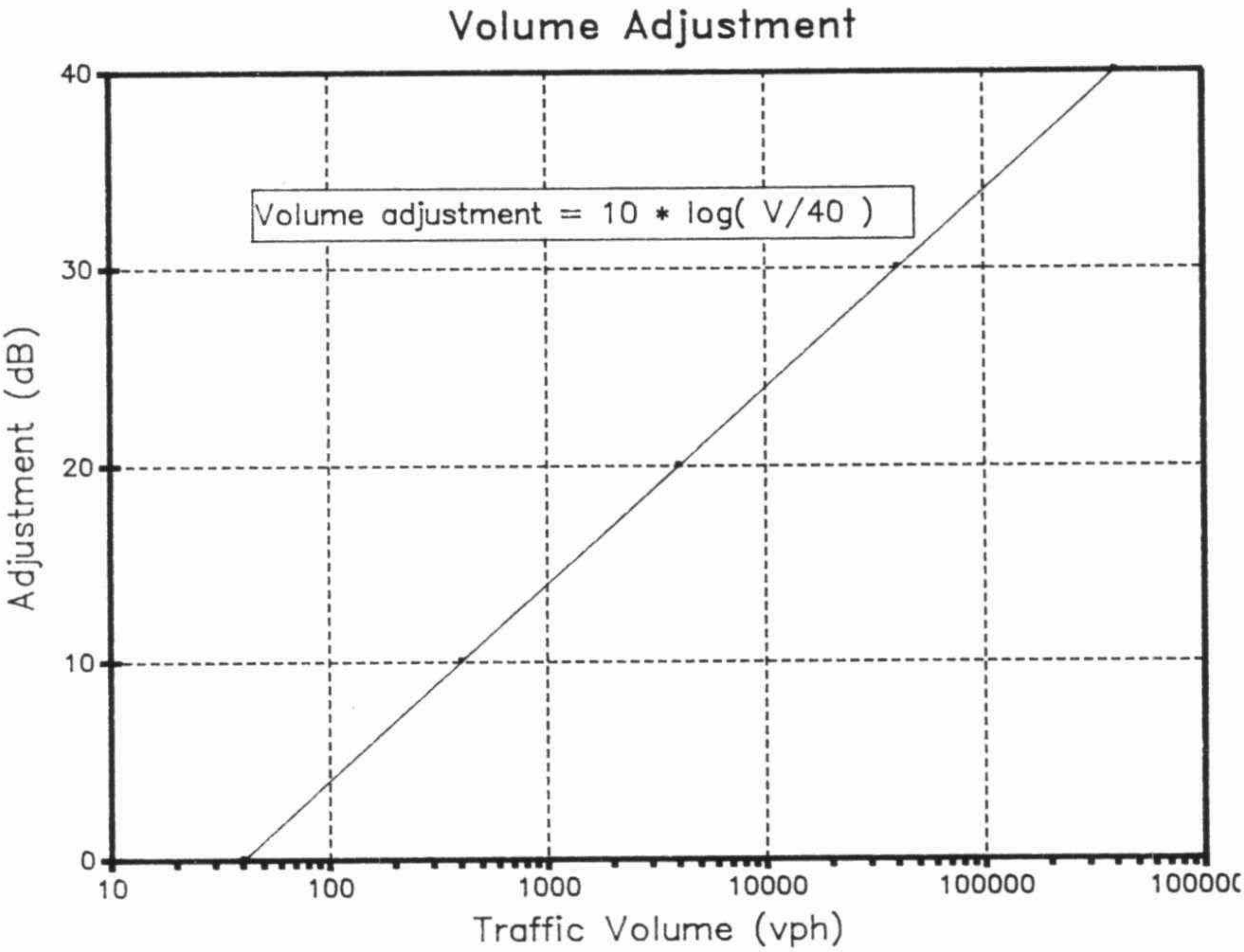


Figure 2: Volume Adjustment

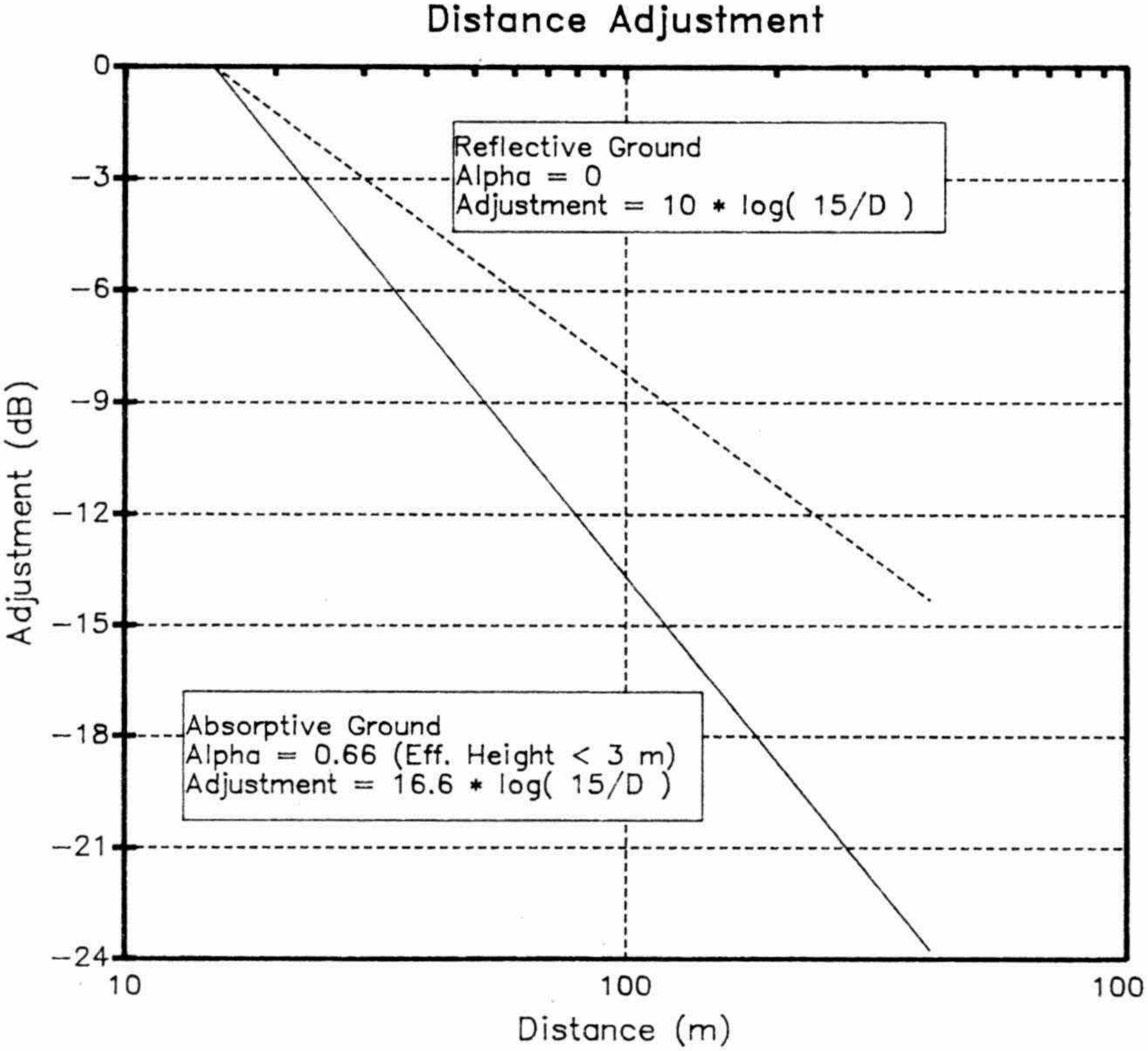


Figure 3: Distance Adjustment

TOTAL EFFECTIVE HEIGHT DEFINITIONS

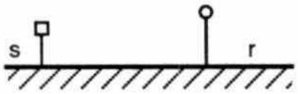
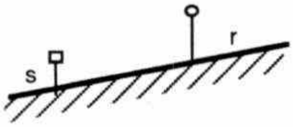
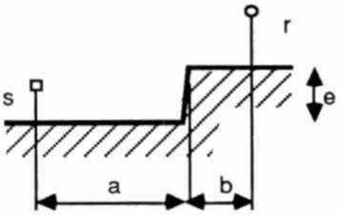
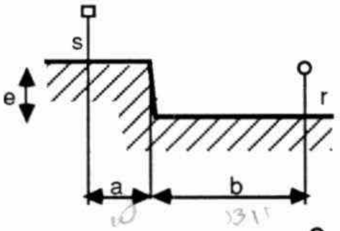
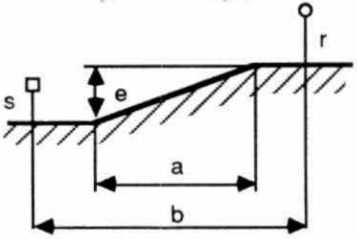
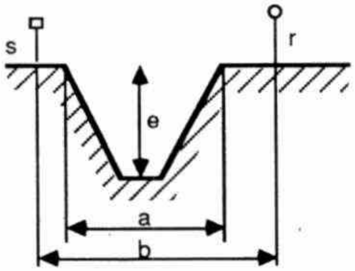
	Topography	Definition
1.		s + r
2.		As 1, s + r
3a.		s + r + e, if b<a/2 s + r, else
3b.		s + r + e, if a < b/2 s + r, else
4.		treat as 2, a > b/2 treat as 3, a < b/2
5.		treat as 1, a < b/2 s + r + 2 e, a > b/2

Figure 4: Definitions of the Total Effective Height for Varying Topographies

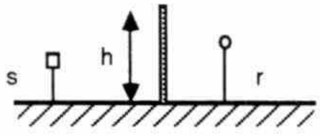
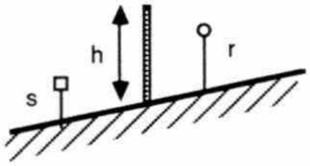
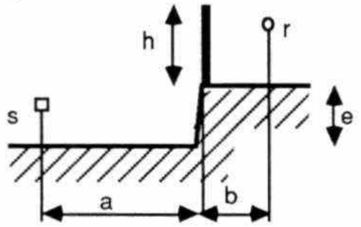
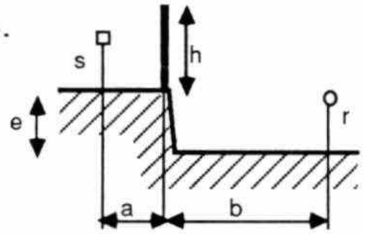
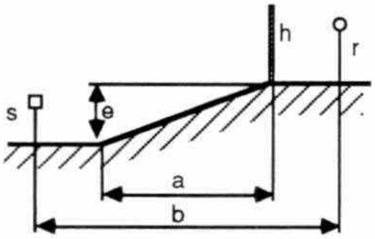
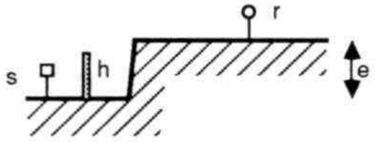
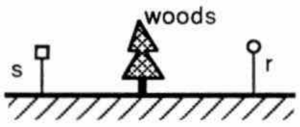
	Topography	**Definition**
6.		s + r + 2h
7.		As 6, s + r + 2h
8a.		s + r + e + 2h, if b<a/2 s + r + 2h, else
8b.		s + r + e + 2h, if a < b/2 s + r + 2h, else
9.		treat as 7, a < b/2 treat as 8, a > b/2
10.		treat as 3, h < e s + r + e + 2 (h-e) , h > e
11.		s + r + 2w , w = 5 m

Figure 4: Definitions of the Total Effective Height for Varying Topographies (cont.)

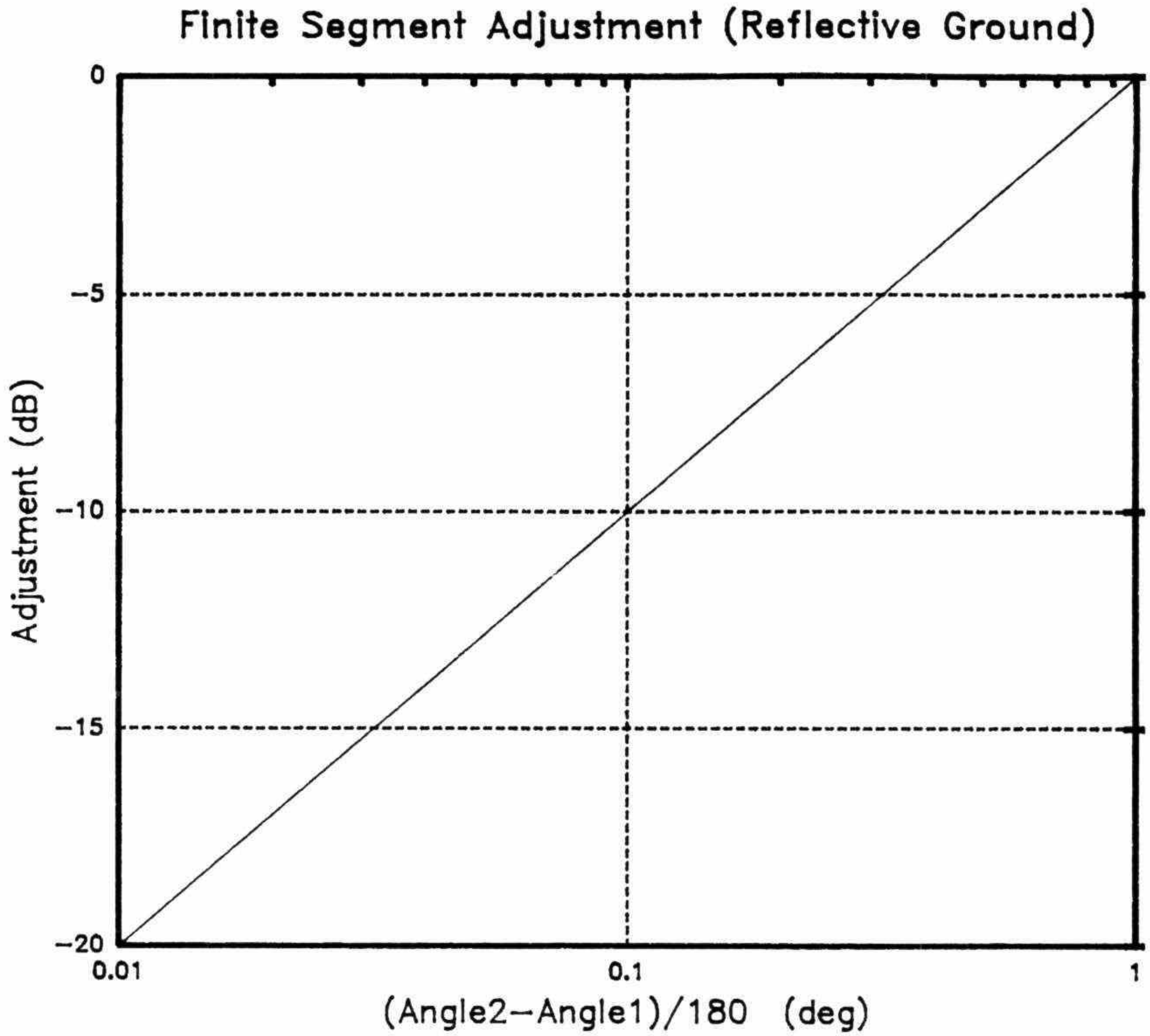


Figure 5: Finite Segment Adjustment (Reflective Ground)

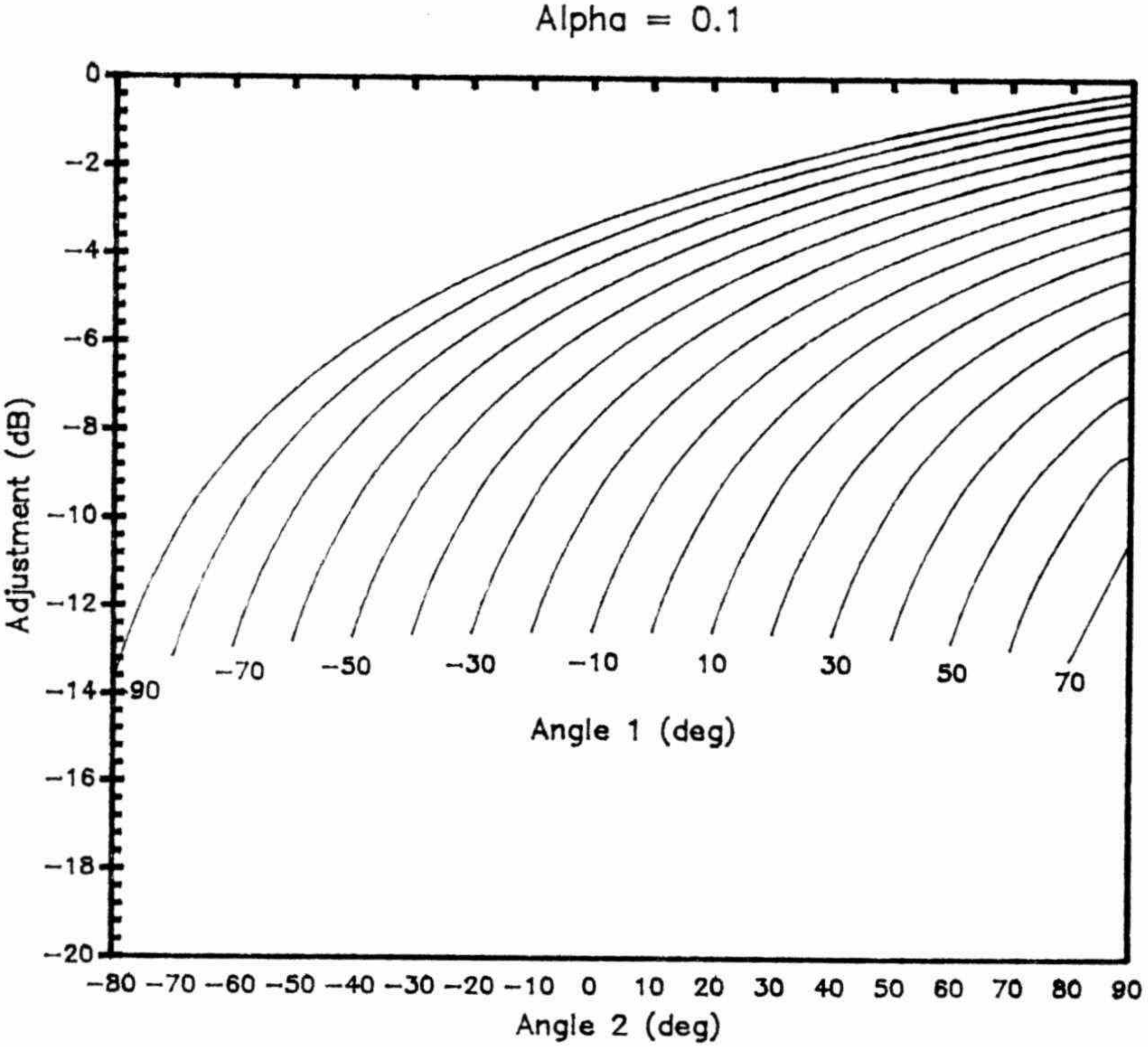


Figure 6.1: Finite Segment Adjustment (Absorptive Ground)
Ground Absorption Coefficient, Alpha = 0.1

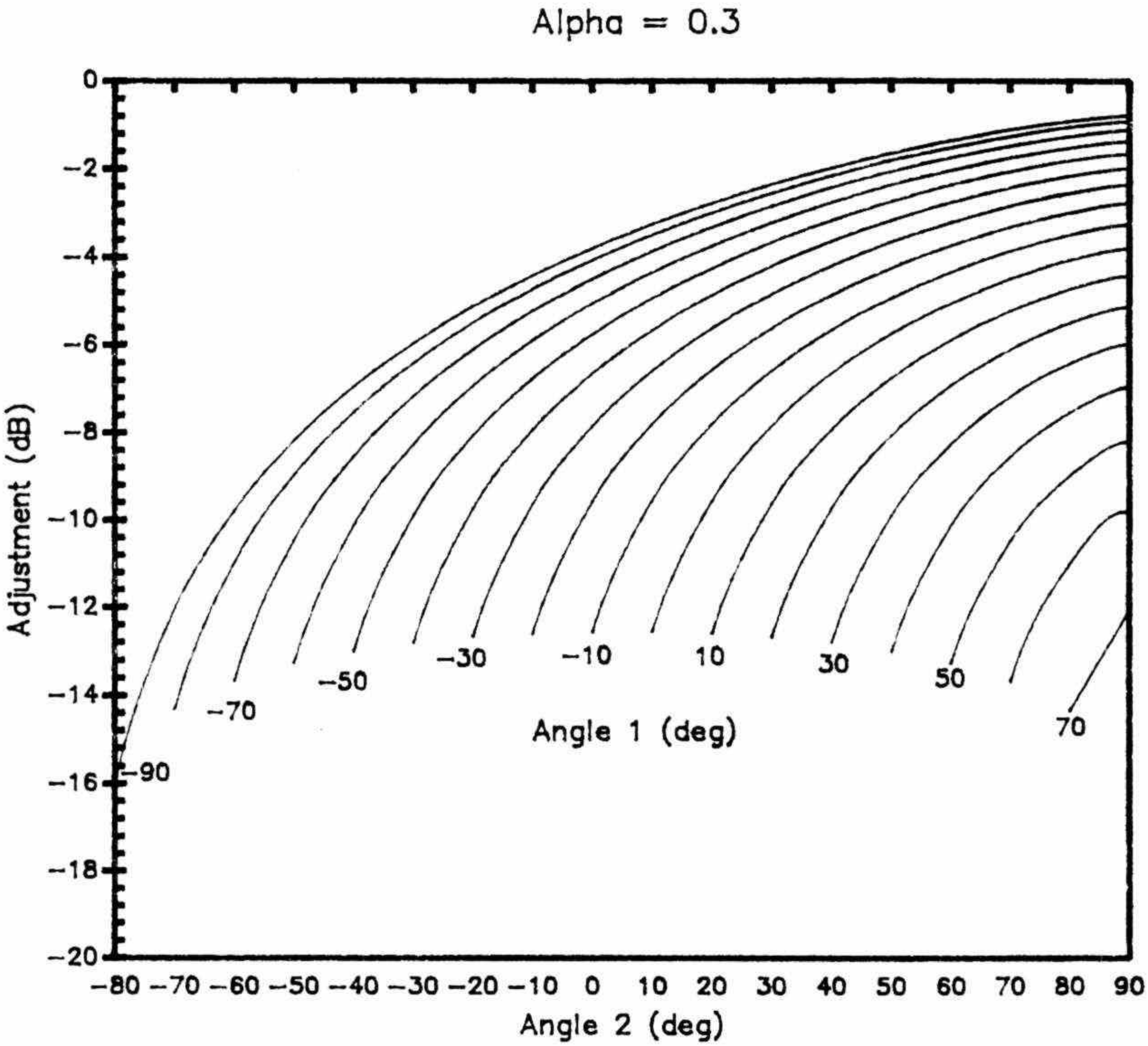


Figure 6.2: Finite Segment Adjustment (Absorptive Ground)
Ground Absorption Coefficient, Alpha = 0.3

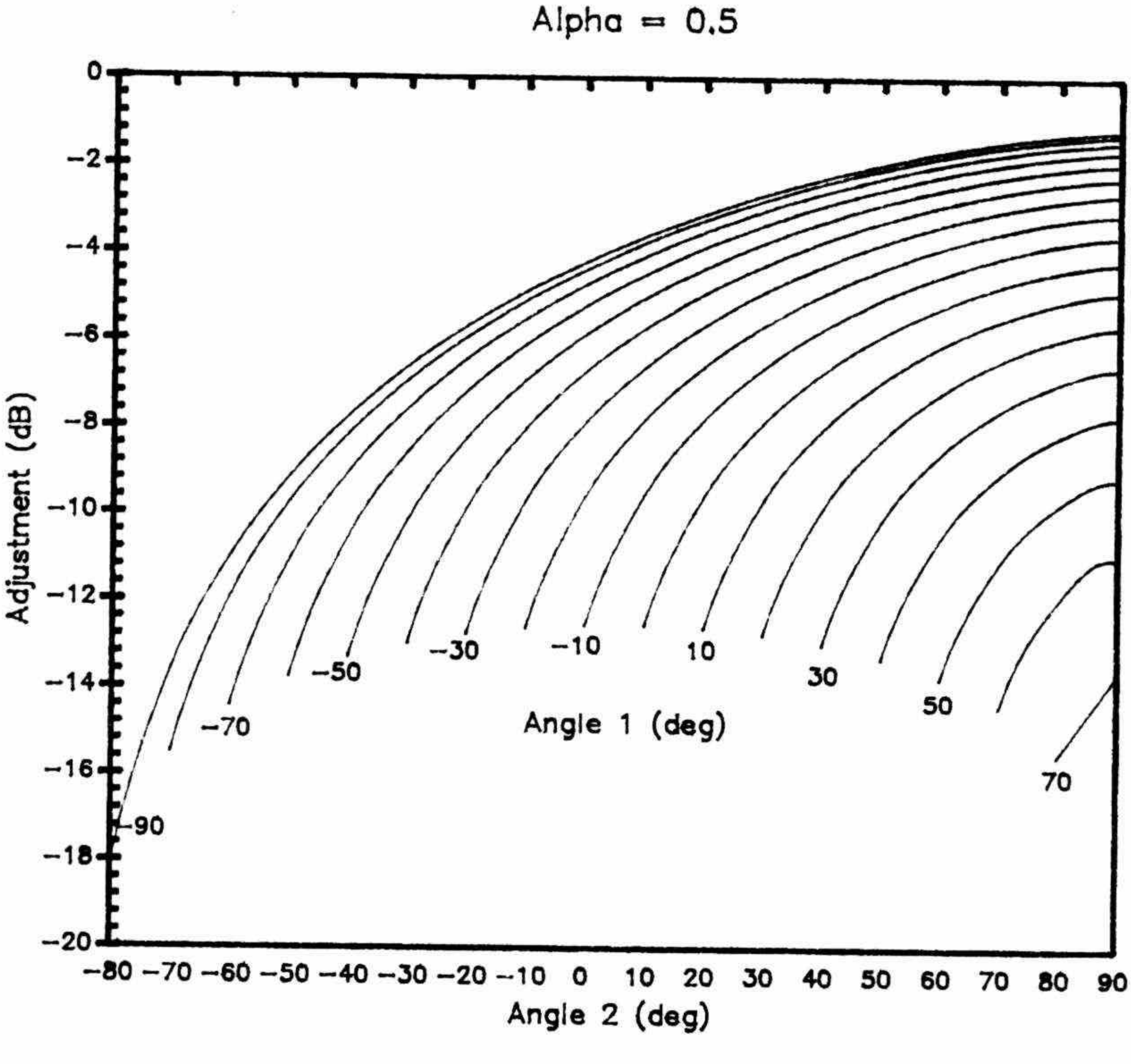


Figure 6.3: Finite Segment Adjustment (Absorptive Ground)
Ground Absorption Coefficient, Alpha = 0.5

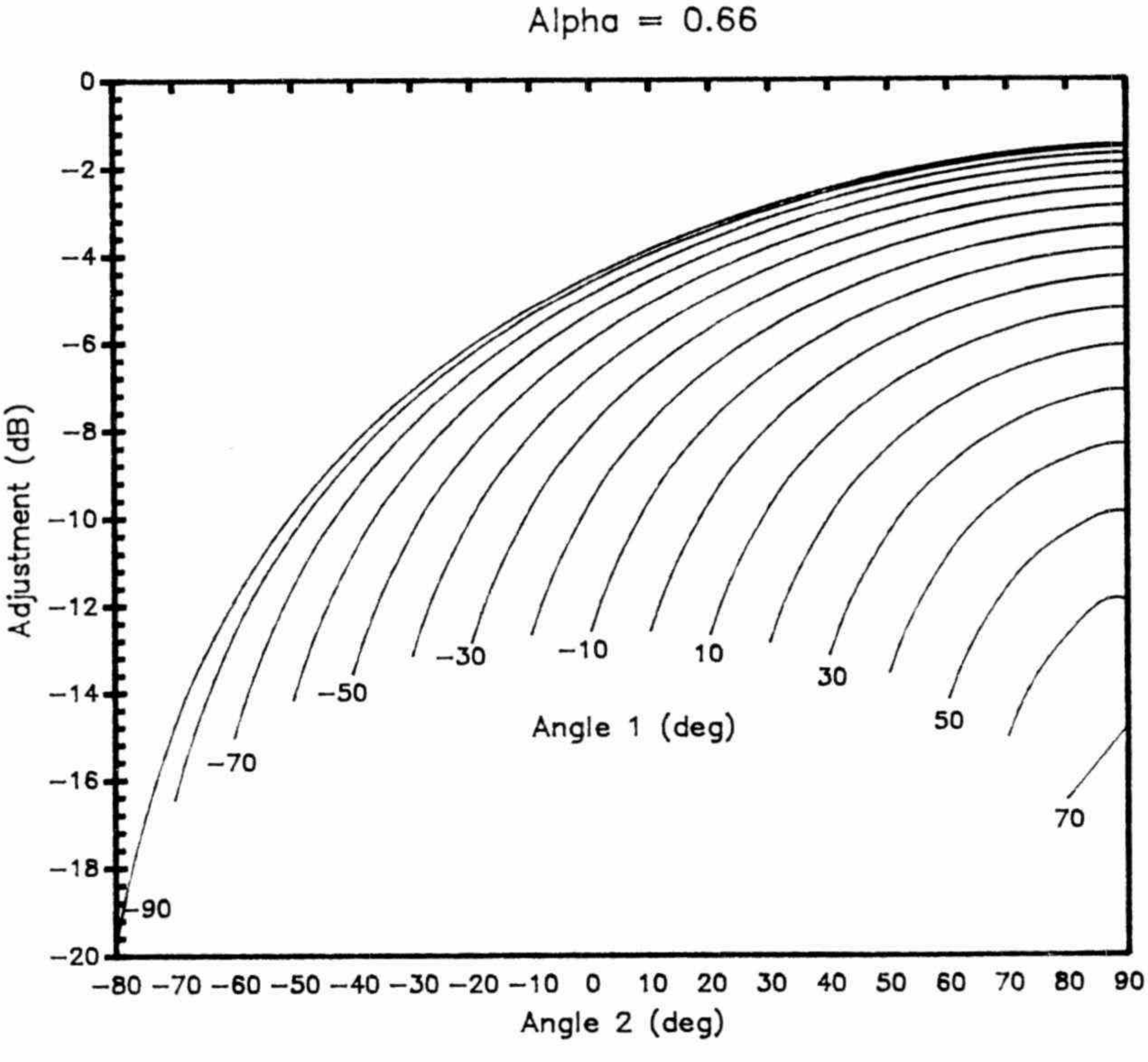


Figure 6.4: Finite Segment Adjustment (Absorptive Ground)
Ground Absorption Coefficient, Alpha = 0.66

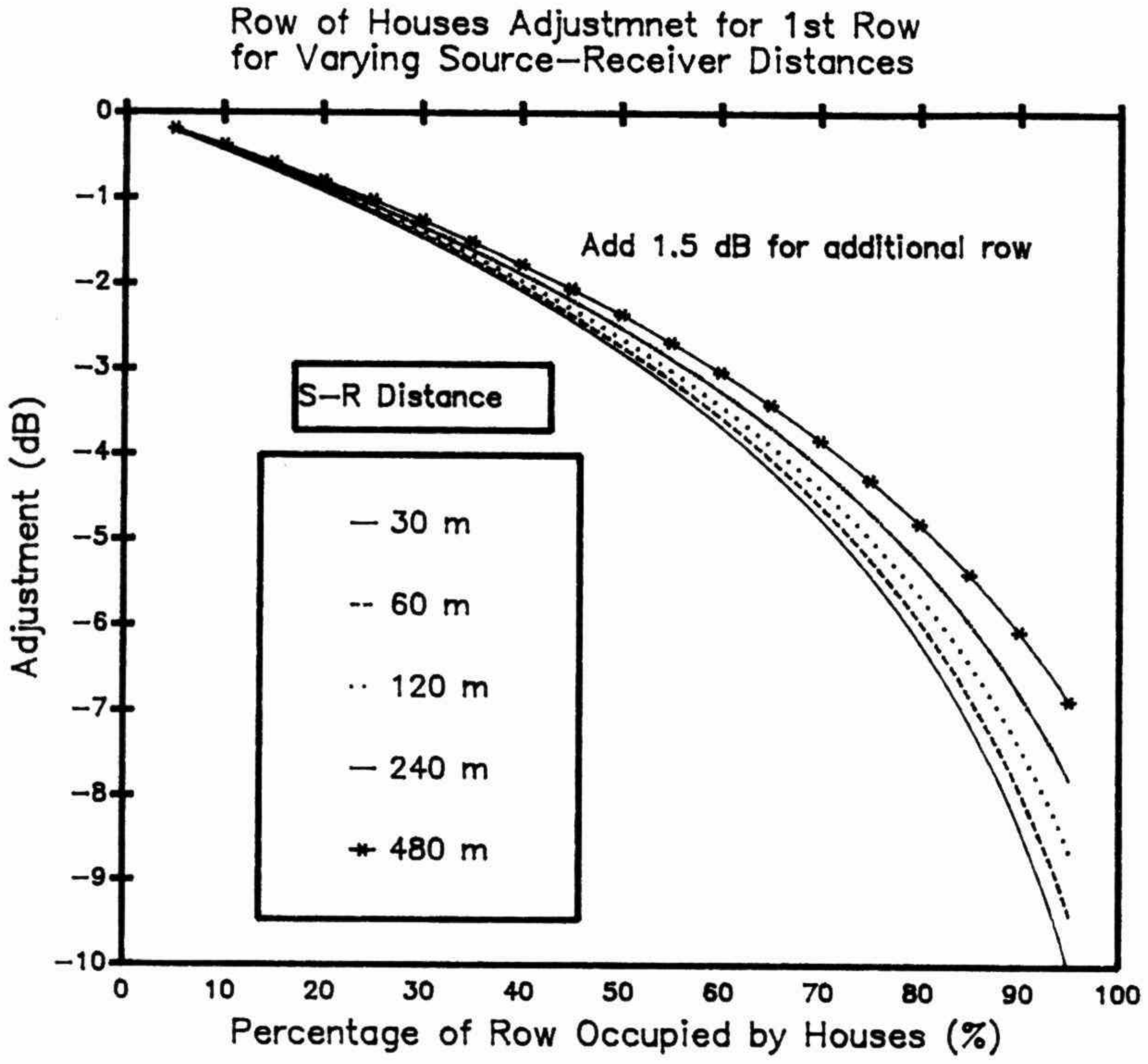


Figure 7: Rows of Houses Adjustment

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